Investigation of the causes of the Reduction of the Full Well Capacity of a CCD for the Dark Energy Camera

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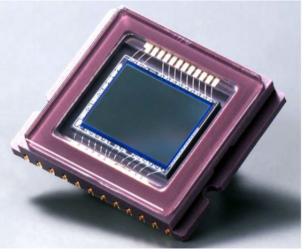
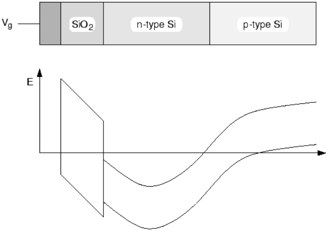
Introduction on CCDs

CCDs (Charge Coupled Devices) are semiconductor photodetectors which, like the other types in this category, exploit electron-hole generation induced by incoming light.

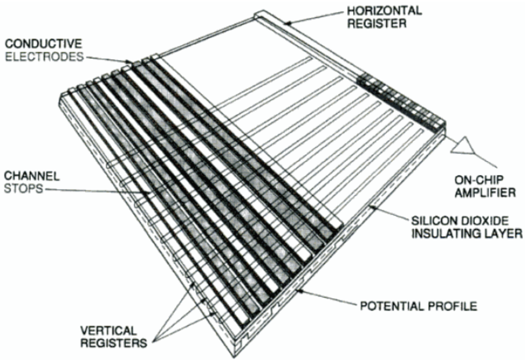
Depending on the type of doping, carriers of one of these two species are collected in a potential well.





Once the exposure ends, this charge is shifted along the columns in which the sensor is divided.

Then each row goes in an horizontal register, the contents of each pixel enters in a capacitor, whose voltage is proportional to the charge, this voltage is amplified by a transistor and converted in digital units by a DAC.



Generally there are 3 electrodes over each pixel: one is at a voltage to generate the potential well, the other 2 for a barrier.

Then, the potential of one of the other 2 is set in a way to broaden the potential well. The charge spreads under both electrodes. This is the reason of the name.

Finally, the voltage of the electrode which initially produced the well is set to have a barrier. The charge has therefore been shifted.

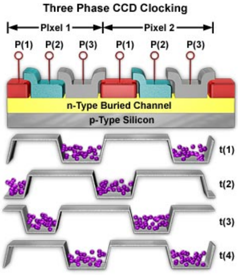
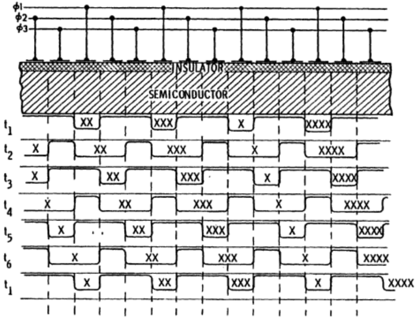
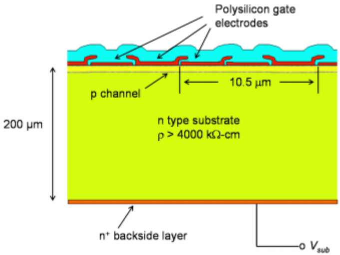


Figure 1

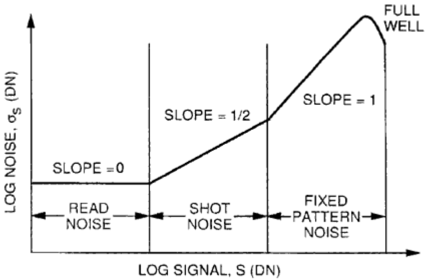


A key factor for an effective operation is a Charge Trasfer Efficiency at least of 0,999995, otherwise too much charge would be lost (a charge packet is travels along thousands of pixels!).
CCDs were originally conceived to be used as memory shift registers, but the former factor makes their fabrication expensive, so they were supplanted by other memory technologies.
They can be front illuminated (light hits on the gate electrodes, which are transparent to visible light) or back-illuminated (better, but more difficult to produce).



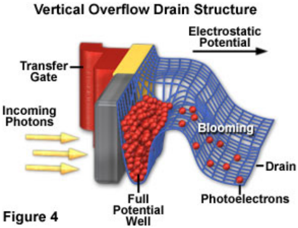
Photon Transfer Curve

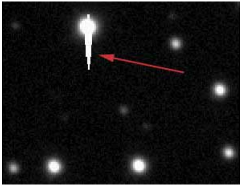
1. Read Noise Floor: due to noise sources independent of the signal level (dark current, amplifier, et c.)
2. Shot Noise: due to the random arrival of photons. Some pixel intercept more photon than others.
3. Fixed Pattern Noise: pixel have different sensitivities because of process variations and errors.



Blooming

Once the full well capacity is reached, the excess charge invades neighbouring pixels on the same columns. This produces bright stripes on the image.





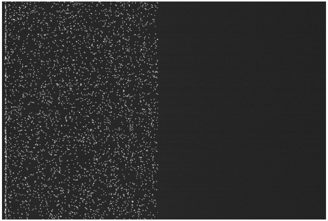
X-rays Calibration

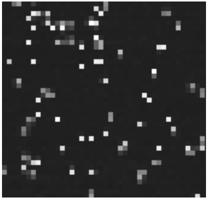
The Photon Transfer Curve is expressed in absolute quantities (electrons), not in arbitrary (digital numbers). But on the image you will read the latter.

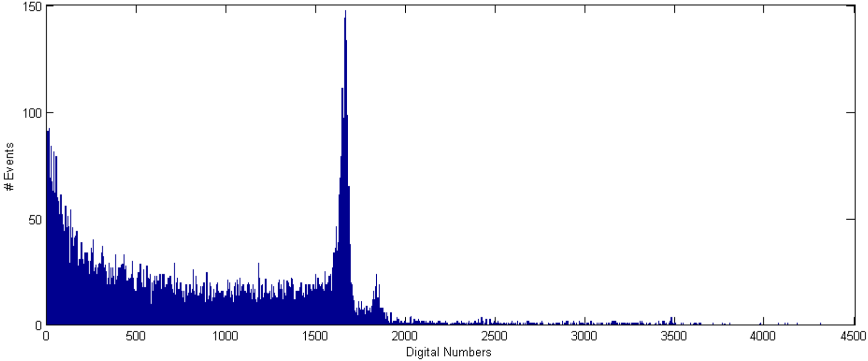
Fe^{55} is a radioactive isotope which emits x-rays of two energies.

The stronger line is K_α, with an energy of 5.9 keV, which produces 1620 electrons.

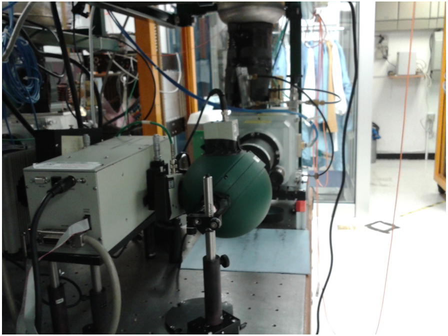
The good thing is that often these electrons are all in the same pixel.






150
100
50
0
Events
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Digital Numbers

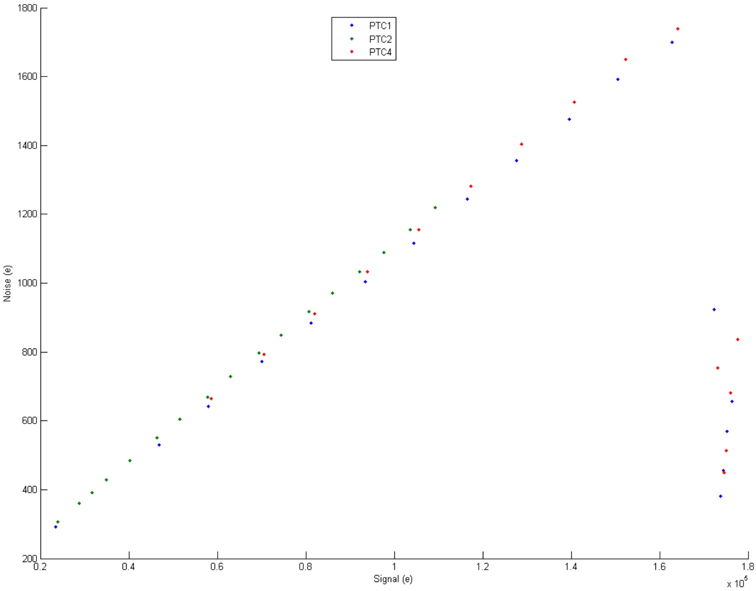
Laboratory Equipment

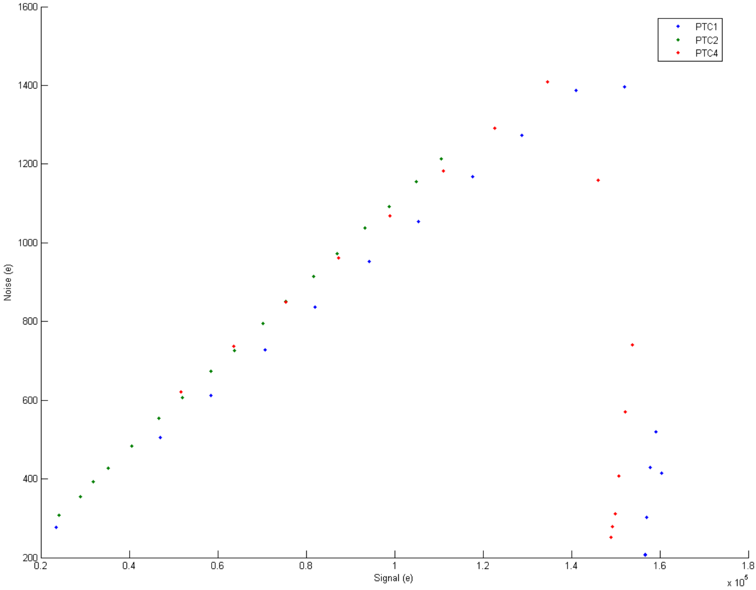


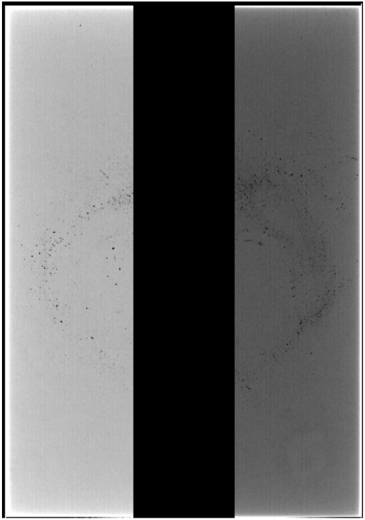
The aim of the experiment was to find which types of damage could produce a reduction of the full well capacity.

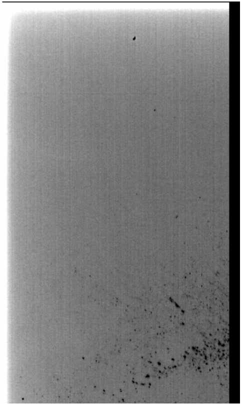
After some initial PTC to find the Full Well Capacity of the healthy CCD, it was exposed for several hours (and then days) to intense light.

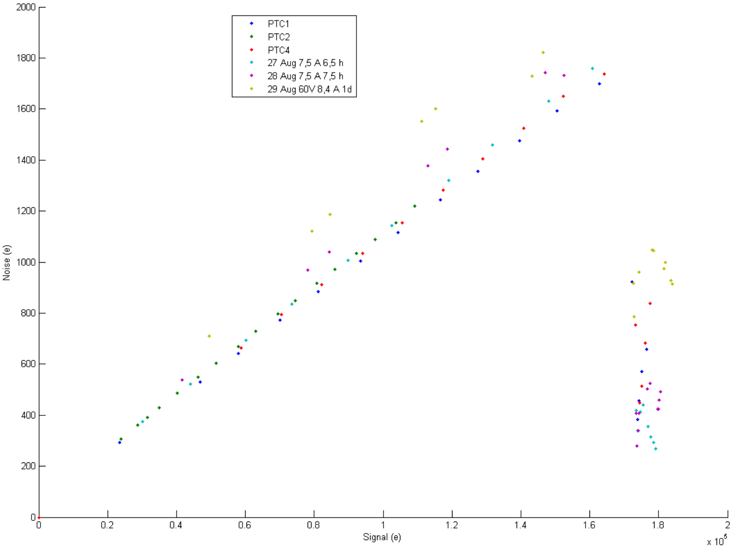
Substrate voltage was increased from 40 V to 50 V and then 60 V because the CCD proved to be quite resilient.


PTC1
PTC2
PTC4
Noise (e)
Signal (e)
x 10^5
1800
1600
1400
1200
1000
800
600
400
200
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8

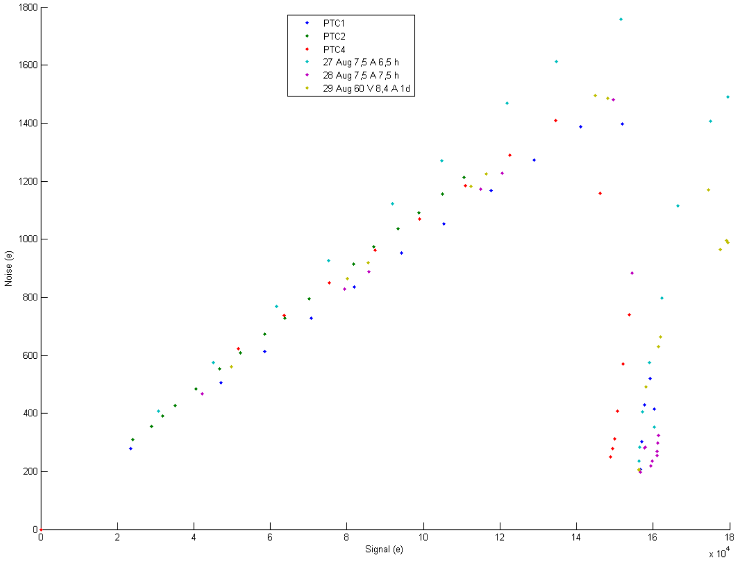

PTC1
PTC2
PTC4
Noise (e)
Signal (e)
x 10^5
1600
1400
1200
1000
800
600
400
200
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8

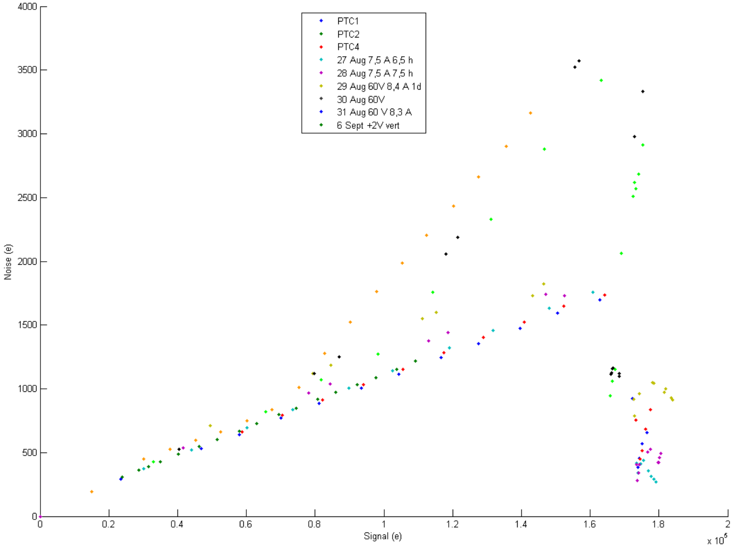


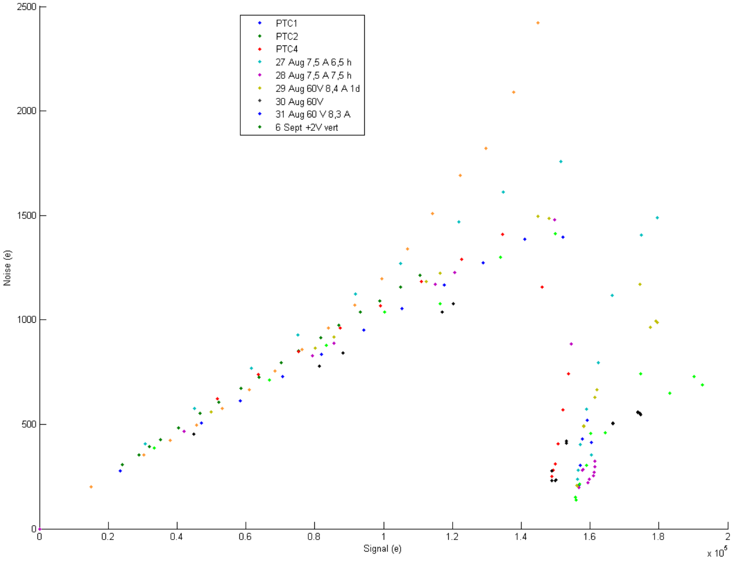


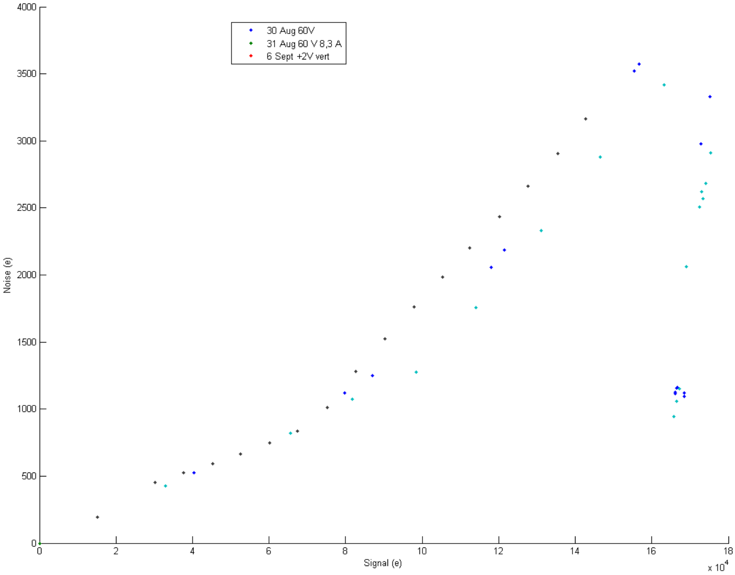


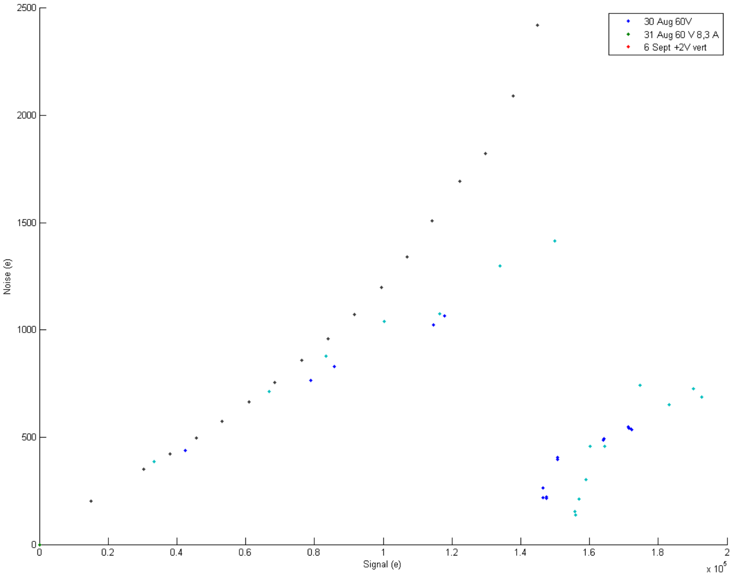
PTC1
PTC2
PTC4
27 Aug 7,5 A 6,5 h
28 Aug 7,5 A 7,5 h
29 Aug 60V 8,4 A 1d
Noise (e)
Signal (e)
x 10^5
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2


PTC1
PTC2
PTC4
27 Aug 7,5 A 6,5 h
28 Aug 7,5 A 7,5 h
29 Aug 60 V 8,4 A 1d
Noise (e)
Signal (e)
x 10^4
0
200
400
600
800
1000
1200
1400
1600
1800
2
4
6
8
10
12
14
16
18


4000
3500
3000
2500
2000
1500
1000
500
0
Noise (e)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Signal (e)
x 10^5
PTC1
PTC2
PTC4
27 Aug 7,5 A 6,5 h
28 Aug 7,5 A 7,5 h
29 Aug 60V 8,4 A 1d
30 Aug 60V
31 Aug 60 V 8,3 A
6 Sept +2V vert


PTC1
PTC2
PTC4
27 Aug 7,5 A 6,5 h
28 Aug 7,5 A 7,5 h
29 Aug 60V 8,4 A 1d
30 Aug 60V
31 Aug 60 V 8,3 A
6 Sept +2V vert
2500
2000
1500
1000
500
0
Noise (e)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Signal (e)
x 10^5


30 Aug 60V
31 Aug 60 V 8,3 A
6 Sept +2V vert
Noise (e)
Signal (e)
x 10^4
4000
3500
3000
2500
2000
1500
1000
500
0
2
4
6
8
10
12
14
16
18


30 Aug 60V
31 Aug 60 V 8,3 A
6 Sept +2V vert
Noise (e)
Signal (e)
x 10^5
2500
2000
1500
1000
500
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

Changing Cloks Voltages

We increased the modulus of the voltage of the vertical, horizontal clocks and of that of the summing well.

X-rays images show a reduction of the smearing.

This suggests that the damage done affects charge transfer.

Maybe the excessive charge was trapped in the oxide and it shields the channel from the applied voltage, that has to be increased.